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CONTAINMENT LEAK SEARCH DURING BRUCE NGS 'A' 1987 STATION OUTAGE

Report No. 87-227-K

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Chemical Research Department

ABSTRACT

To minimize radionuclide dispersion at nuclear generating stations the containment volume is maintained at negative pressure and the containment boundary is periodically pressurized to test for leakage. Tracer gas, ultrasonic and leakage catcher techniques were used recently as a test during the four-unit outage at Bruce NGS 'A' to identify and quantify containment leakage. A 3 % ethylene in nitrogen mixture was injected into containment during the pressure test and over 290 samples of station air were collected and analyzed for evidence of the tracer gas. Tracer gas measurements indicate that the largest source of leakage, accounting for approximately 25% of the total measured leakage, arose from the boiler room areas and auxiliary areas on elevations 678' and 693' of units 2 and 4. Although soap solution spraying appeared to be more efficient at locating the Type 1,2 and smaller Type 3 leaks, flow measurements obtained with the leakage catcher indicate that these smaller leaks represent less than 6% of total measured leakage. Ultrasonic techniques were available for leak searching in the fuelling machine duct, but dose considerations precluded their use in view of the overall leakage not exceeding safety analysis levels.

job	file	date	report no.
32-050	835.6212	June 7, 1988	87-227-K



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EXECUTIVE SUMMARY

CONTAINMENT LEAK SEARCH DURING BRUCE NGS 'A' 1987 STATION OUTAGE

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A physical containment barrier minimizes the potential release of radionuclides from nuclear plants. Periodic tests are required by the AECB to demonstrate both the integrity of the containment boundary at Ontario Hydro's nuclear generating stations and that the air leakage is less than 2% per hour at design pressure. As part of the May, 1987 BNGS 'A' outage a pressure test was conducted during which the entire containment volume (reactor vaults, fuelling machine ducts and service areas) was pressurized and the leakage rate measured at various pressures. Concurrently a search for leakage sites was conducted.

The conventional technique for leak detection, spraying soap solution at the suspected leaksite, is limited in application and is both time- and labour-intensive. In the present study an ethylene tracer gas was injected into containment to achieve an internal concentration of approximately 50 uL/L. Subsequent analysis of station air revealed fifteen areas having elevated tracer gas levels including the vacuum building basement, several boiler rooms and the non-contaminated ventilation stacks in Units 2 and 4.

Several of the Type 3 leaks detected by soap solution were quantified, using the recently developed leak catcher device and found to be negligible compared to the total measured leakage. The leakage suggested by tracer gas measurements in the non-contaminated ventilation was estimated to constitute the bulk of the 35% of total leakage which was accounted for by the various techniques used. The remainder of the leakage may escape via inaccessible areas such as the fuelling machine and pressure relief ducts.

Recommendations are proposed for future work to refine the tracer gas method of leak detection.

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32-050	835.6212	June 7, 1988	87-227-K



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To: Mr. R. Coutts
Station Manager
Bruce NGS A - Operations

CONTAINMENT LEAK SEARCH DURING
BRUCE NGS 'A' 1987 STATION OUTAGE

T.G. Pringle, T. Jarv and B. Handy

1.0 INTRODUCTION

A physical containment barrier at Ontario Hydro's nuclear generating stations minimizes the potential release of radionuclides. Periodic tests are required by the AECB to demonstrate both the integrity of the containment boundary and that the air leakage is less than 2% per hour at design pressure. In order to reduce dispersion of contamination, the reactor vault system at Ontario Hydro's stations is maintained at approximately 3 kPa below atmospheric pressure. To maintain negative pressure within the containment structure the inleakage operating specification for Bruce NGS 'A' is <1% of total contained volume per hour (2680 kg/hr) at 69 kPa. As part of the May, 1987 outage a pressure test was conducted during which the entire containment volume (reactor vaults, fuelling machine ducts and service areas) was pressurized and the leakage rate measured at various pressures. Concurrently a search for leakage sites was conducted.

The conventional technique employed to locate leaks has been the application of soap solution to suspected areas and subsequent observation of the rate of bubble formation resulting from escaping air. However, this method is limited to known or suspected leaksites such as penetrations or cracks in concrete, is labour- and time-intensive, is incapable of detecting leaks in inaccessible areas of the station and provides approximate flow rates and then only for relatively small leaks.

A multi-year research effort, co-funded by CANDEV, has been underway to develop improved techniques both to locate leaks and to determine the leakage rate at a specific site. Laboratory investigations and in-plant tests have been carried out to study alternate techniques such as tracer gas, ultrasonic detection and direct leakage rate measurement, respectively/1-4/. The 1987 four unit Bruce NGS 'A' pressure test was an opportunity to apply

these new techniques under field conditions with the objective of determining to what extent the potential advantages of tracer gas leak detection could be used in a large operating nuclear station to complement or supplant traditional soap solution techniques. In addition the leakage catcher and ultrasonic detection techniques were available as operational tools to determine the significance of identified leaks and locate leaks in underground areas of containment, respectively.

1.1 Strategy

The leak detection approach was tailored both to detect unexpected leaks and to locate specific leaks within a period of 4-6 hours allotted during the pressure test, thus preventing delay in the pressure test. Tracer injection into containment occurred during the pressurization period and in the subsequent stabilization phase air samples were taken throughout the station using plastic bags. These samples were located close to known containment penetrations, near auxiliary systems and in areas which might indicate leakage due to poor isolation. To ensure thorough sampling of the air throughout the entire station, 236 sample sites were identified from an examination of station floorplans and consultation with station personnel. Once these area samples were analysed by sensitive gas chromatography, portable photoionization detectors (TIPs) were available to conduct area sampling and sample in the vicinity of the more serious leaks identified from the bagged samples and locate specific leaksites.

In order to determine if a particular leakage site is a significant contributor to the total station leakage, and consequently whether repair is worthwhile, reliable quantitative estimates of the leakage rate were obtained using the leakage catcher developed previously. This device and its calibration are more completely explained elsewhere/4/.

Several locations in the station are not amenable to the application of soap solution or the measurement of tracer gas since the exterior of the containment boundary is underground (eg. the north side of the fuelling machine duct on elevation 579'). In these situations the ultrasonic noise created by escaping turbulent airflow can be detected and two parabolic ultrasonic detectors were available for leak searching of the fuelling machine duct (FMD) and pressure relief ducts/3/.

1.2 Tracer Gas Selection

Although SF₆ has been used successfully as a tracer in the past, fears of potential corrosive effects of its decomposition products necessitated a replacement gas. The four likely candidate tracers listed in Table 1 were selected from an examination of many gases including perfluorocarbons, halocarbons, hydrocarbons, noble gases and inorganic gases/5,6/.

TABLE 1

TRACER GAS CANDIDATES FOR LEAK DETECTION*

TRACER	VAULT CONCENTRATION (uL/L)	DETECTION LIMIT (uL/L)	VAULT/ DETECTION LIMIT RATIO	TRACER* COST (\$)	INSTRUMENTS
SULFUR HEXAFLUORIDE (SF ₆)	50	0.02 (PORTABLE) 0.03 (CENTRAL)	2 500 30 000	\$1 000	(PORTABLE IR) GC (CENTRAL)
ETHYLENE (C ₂ H ₄)	50	0.1 (PORTABLE) 0.005 (CENTRAL)	500 10 000	\$3 800 (GAS)	PHOTOIONIZATION DETECTOR (PORTABLE) (CENTRAL)
HELIUM (He)	2 500	10-12 (BACKGROUND)	250	\$5 300 (GAS)	THERMAL CONDUCTIVITY DETECTOR (PORTABLE)
TRITIUM (³ H)	0-3000 uCi/m ³ HIGHLY VARIABLE	1 uCi/m ³ (PORTABLE) 0.02 uCi/m ³ (CENTRAL)	0 - 3000 0 - 10 ³	0	TRITON 955B (PORTABLE) BERTHOLD LB106B PROPORTIONAL COUNTER
XENON-131 (¹³¹ Xe)	0-20 uCi/m ³ VARIABLE	10 ⁻⁶ - 10 ⁻³ uCi ON CHARCOAL FILTERS	-	0	NONE PORTABLE - SPECTROMETER (CENTRAL)

* 4 UNIT (10⁵ m³) BRUCE STATION

Consideration was given to ease of detection, flammability, toxicity, ease of handling and corrosive effects. The poor vault/detection limit obtainable with practical amounts of helium injection and a lack of a sensitive central detector precluded the use of this gas. Furthermore, leaks from the helium-filled cover gas system would also interfere with leak detection. Both xenon and tritium have insufficiently stable containment concentrations to be useful and no portable detector exists for xenon. Ethylene, which has none of the corrosive decomposition products of SF_6 and which can be detected relatively easily by central or portable instrumentation, was the most suitable tracer candidate. Suitable tracer injection parameters, an analysis of reactor systems and tests on the molecular sieve used in the vault driers ensured that flammable concentrations of the tracer would not exist.

2.0 EXPERIMENTAL

2.1 Pre-outage Experimentation

Ethylene is a compound that is relatively well adsorbed by the molecular sieve used in the vault drier circuits at Ontario Hydro nuclear generating stations. Tests were therefore conducted prior to the outage to confirm that ethylene would not accumulate to within flammable concentrations in the driers or drier regeneration circuits. The results indicate that the maximum concentration of ethylene in the drier regeneration circuit would be approximately 1.3 mL/L. The lower explosive limit of ethylene is 31 mL/L. The details of these tests are provided in Appendix 1.

2.2 Tracer Gas Injection

A 30 mL/L mixture of ethylene (lower explosive limit (LEL) of 31 mL/L of air) in nitrogen was injected from 35 cylinders via manifold into the air pressurization lines immediately upstream of the system outlet (EP 1057) on vaults 1, 3 and 4 and directly into vault #2 via EP 1057. Custom manifolds and high flow Victor regulators were used to allow injection of 213,500 litres of the ethylene mixture within the pressurization period of approximately 2 hours. Injection of the tracer into the pressurization air facilitated mixing in containment. The apportioning of tracer gas amongst the various inlets is illustrated in Figure 1. The tracer concentration was projected to be 58 uL/L at a pressure of 13.8 kPa in containment.

2.3 Tracer Gas Sample Collection and Analysis

Over 290 air samples were collected, using battery-operated pumps, in polyvinyl fluoride bags from various locations and subsequently analyzed for ethylene using a very sensitive gas chromatograph located in a trailer situated between reactors 3 and 4 on elevation 615'. Details of the analytical equipment and

Legend

-  Soap Solution Only
-  Tracer Gas, then soap
-  Ultrasonic (Only if required)

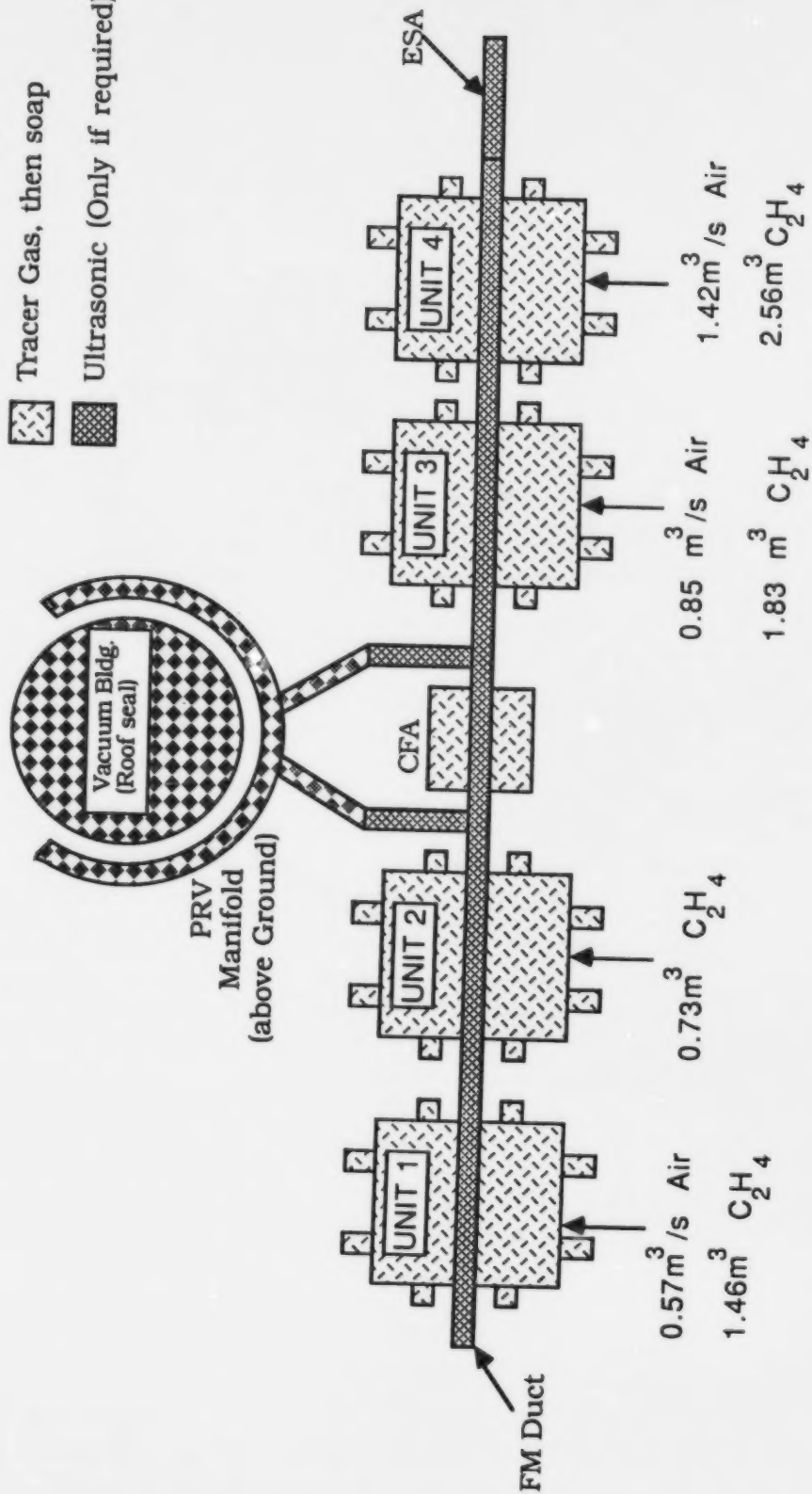


Figure 1

Recommended Leak Search Methods and Tracer Gas Distribution

protocol are available in Appendix 2. Portable photoionization detectors were to be utilized for locating the specific site of the leakage. Trial operation of these detectors indicated that they would provide detection capability only at short range.

3.0 RESULTS

Out of the initial 236 sampling sites, samples were successfully obtained from 201 sites at a vault pressure of 6-13.8 kPa. A further 54 samples were taken from suspicious locations or as repeat samples at various pressures during the remainder of the test. As described in Appendix 2, the analytical results were classified as being in one of three categories, trace or negligible amounts of ethylene, detectable amounts of ethylene or measurable amounts with the concentration of tracer reported only in the latter case. Of the total of 290 samples, 49 had concentrations which were quantifiable (see Table 2) and 216 contained only a trace or no ethylene.

The concentration of ethylene inside containment was found to be 41 uL/L. This figure differs from the calculated 58 uL/L because of further pressurization prior to the sampling period and, more importantly, because of undetected leakage through the service central service area vapour recovery system dampers which were left partially open during tracer injection. Approximately 3000 kg/hr of air and an unknown amount of tracer was being released from the contaminated exhaust stack during this period (approximately 2.5 hours).

Following the location of 45 Type 3 leaks by the soap solution crews (defined to be leaks for which the application of soap solution results in severe foaming, blowoff of solution, audible hissing or air flow sensed by hand/7/), the leakage catcher was used to quantify the leakage rate of seven of these to determine their significance to the total leak rate and thus the urgency to repair them. Table 3 lists Type 3 leak rates ranging from 0.009 kg/hr to 0.029 kg/hr and two transfer chamber isolation leaks of 8.0 and 10.1 kg/hr.

4.0 DISCUSSION

4.1 Tritium/ethylene Comparison as Tracer Candidates

To allow the use of tritium as a tracer it would be necessary for tritium concentrations to be proportional to the leakage of vault air. The ratio of tritium to ethylene tracer gas would be relatively constant if this were the case. Using tritium measurements taken by station staff and tracer gas data, tritium/ethylene ratios were calculated where comparable measurements were available. It is evident from Table 4, that

Table 2

Summary of Tracer Concentrations Found During Pressure Test

Sample	Tracer Concentration nL/L	Location and Comments
A	0 - 6	Typical reactor auxiliary bay sample (trace).
B	9 - 30	Vicinity of two Type 3 leaks (69 kPa) on fuelling machine duct wall east of Unit 4 on elevations 579' (18 nL/L) and 591' (9 - 27 nL/L). Leak on 591' measured by leak catcher at 0.0087 m3/hr.
C	5 - 14	East boiler room, Unit 2.
D	12 - 16	Unit 4, West boiler room; Type 3 leak (69 kPa).
E	4 - 19	Unit 4, East boiler room.
F	14	Downwind of a Type 3 leak (69 kPa) in nearby HT auxiliary room in Unit 1 (no direct sample available), 639' elevation.
G	16	Unit 3 West boiler room.
H	17	Found in noncontaminated exhaust stacks in both Units 2 and 4.
I	6 - 18	Along wall between ST19 and Active Liquid Waste Handling tanks, 8 EP's in vicinity, 18 nL/L elevation 579', 6 nL/L elevation 595'.
J	18	Main HT pump area north, Unit 2, elevation 678'.
K	19	East boiler room, Unit 3; Type 3 leak (69 kPa).
L	30	Unit 3 inside Heat Transport Aux. Room.
M	40 - 80	West boiler room, Unit 2.
N	90 - 130	Moderator rooms in Unit 3 except Rm 112.
O	20 - 600	Vacuum building basement, in vicinity of VP6 - VP18.

Table 3

Leakage Rates Measured by the Leak Catcher

Sample	Measured Flowrate (kg/hr)	Leaksite Description
A	0.029	Expansion joint east of Unit 3, elevation 579' FMD wall.
B	0.028	Expansion joint east of Unit 3, elevation 600' FMD wall.
C	0.0087	Penetration EP 17058, east of Unit 4 elevation 615', FMD wall.
D	0.013	Expansion joint auxiliary coolant injection room Unit 3, elevation 579'.
E	0.03	VP12 valve, vacuum building basement.
F	8.0	Fuelling machine transfer chamber #1 equalization ports, service building, elevation 615'.
G	10.3	Same as F except transfer chamber #4.

the ratios of these two materials varied considerably depending on the location and time of analysis. This was expected since tritium levels in containment will vary with location, time elapsed since shutdown and ventilation rates. To use tritium as a tracer for leak detection it would be necessary to take tritium measurements in all contained areas on a continuous and consistent basis - an impractical undertaking. The relatively poor lower detection limit for tritium (0.35 MPCa obtained in the vacuum building basement would cause, at least, further difficulty in the detection of relatively small Type 3 leaks since a sizeable leak would be required to enable detection. In the worst case a combination of poor detectibility and low local tritium concentrations within containment could prevent detection of a significant leak. Thus tritium can be excluded from further consideration as the primary tracer.

4.2 Comparison with Type 3 Leaks

Of the 45 Type 3 leaks identified by soap solution crews at 69 kPa, 17 were also indicated by tracer gas, 6 at the 6 kPa pressure level and a further 11 at the 69 kPa level. Apart from these 17 areas identified by both soap solution and tracer gas, another 10 areas showed indications of elevated tracer gas

Table 4

Ethylene/Tritium Ratios

Location	Ethylene/Tritium Ratio ((nL/L)/MPC(a))		
	May 12 (~0 kPag)	May 14 (~30 kPag)	May 15 (~30 kPag)
Vault 2	1.4	-	-
Boiler Room 2	-	8.8	21
Vault 4	1.5	-	-
Boiler Room 4	-	25	-
VP Basement	-	<3.2	-
Moderator Rooms	-	-	0.05

concentrations (see Table 2). The only Type 3 leak with a leak catcher measurement and nearby tracer samples is EP 17058 (Sample B, Table 2 and sample C, Table 3). Although a nearby EP 1906 also is listed as a Type 3 the magnitudes and locations of several tracer measurements indicate that EP 17058 is larger. However the unquantifiable influence of ventilation, the size of the leak and the proximity of the two leaks preclude a direct comparison between the tracer measurements and the Type 3 soap solution results.

Some areas which showed negligible or trace contamination by ethylene during the initial search at 6 kPa had markedly higher concentrations at 69 kPa (eg. unit 2 and unit 4 boiler rooms). This would suggest that in addition to a tracer gas search at 13.8 kPa to enable initial testing decisions to be made it would be very useful to obtain more extensive data from tracer gas sampling at 69 kPa.

It is interesting to note that leaksite B in Table 3 was easily detected despite the low flow (0.0087 kg/hr) while a Type 3 leak at EP 1711 (0.013 kg/hr) was not detected unless samples were taken within 0.5 m of the site. Clearly the ability of the tracer gas technique to indicate smaller Type 3 leaks is strongly dependent on the position of sampling, the containment pressure and the time for gas diffusion to establish patterns. Studies of tracer gas dilution would be helpful in refining the operational limits of the technique.

4.3 Vacuum Building Basement

Tracer gas was detected at relatively high levels in the vacuum building basement. At an early stage in the test a vent duct flapper valve was found to be passing. The proportional decrease in tracer concentrations with distance from this valve confirms this leak as the major source of tracer gas in the VB basement. Although the valve was subsequently sealed, a combination of poor ventilation and continuing slow leakage from several vent duct penetrations prevented significant reductions in the tracer gas concentration.

4.4 Moderator Rooms

In the early stages of the test it was decided that tracer gas analysis in the moderator rooms would reduce personnel exposure to tritium, when compared to soap solution spraying. Measurements taken in the seven rooms of Unit 3 showed elevated concentrations in all but one of the rooms. The use of the confinement driers to reduce tritium levels in these rooms spread the ethylene throughout all of the unit 3 moderator rooms on elevations 579' and 591' except Rm 112 which was not connected to the drier circuit. Subsequent soap solution application indicated an EP with a relatively large Type 3 leak. The tritium levels were also measured and found to exceed 2000 MPCa.

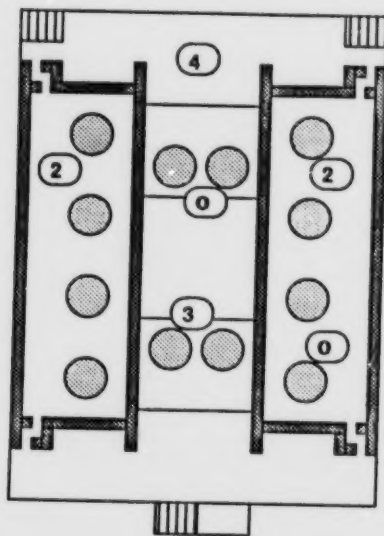
4.5 Boiler Rooms and Elevation 693'

One of the areas of the plant which had elevated ethylene concentrations and could be the source of significant leakage are the boiler rooms, particularly in Unit 2. Measurements taken during the first tracer search at 7 kPa indicated small amounts of tracer in the boiler rooms of Unit 3. Later measurements taken at 69 kPa indicated elevated tracer concentrations in the boiler rooms of both Unit 2 and Unit 4 (see Figure 2). During the outage the ventilation to these boiler rooms was periodically operated through the confinement driers to reduce elevated tritium levels, a further sign of the presence of a leak. At other times the prevailing ventilation flows would presumably carry this leakage towards the 678' and 693' levels and eventually be picked up by the roof fans and exhausted through the non-contaminated stack.

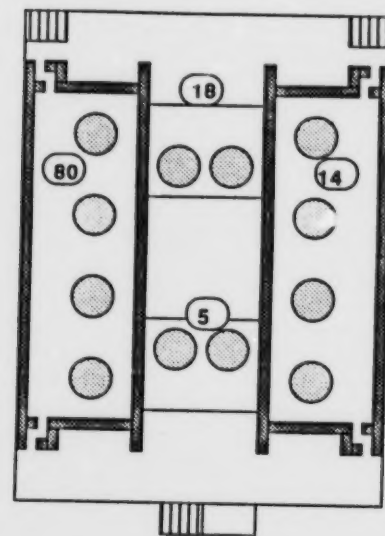
Several air samples taken from the vicinity of the primary heat transport pump penetrations showed no evidence of tracer gas. Thus the seal integrity for these penetrations was confirmed and removal of the shield blocks around the pumps, a time-consuming process, was avoided.

4.6 Evaluation of Leakage Results

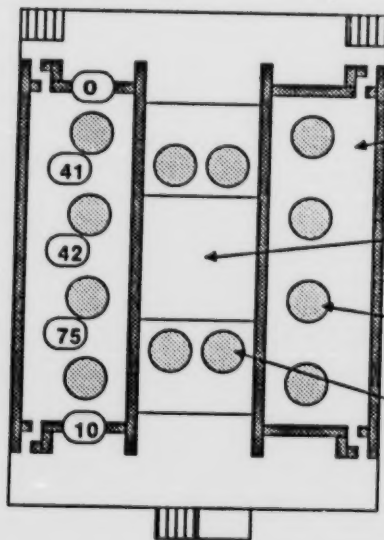
Obviously the Type 3 leaks are insignificant when compared to the total plant leakage of 1600 kg/hr at 69 kPa/8/. Even if all 1800



May 12
6-14 kPa



May 14
30 kPa



May 15
69 kPa

Boiler Room

Reactivity Mechanisms
Deck

Steam Generators

PHT Pumps

N
↑

Legend

(10) Concentration of tracer gas
in nL/L

Figure 2
Tracer Concentration in Unit 2 - Elevation 678'

penetrations in the plant were to leak at the highest leak rate found by the leak catcher (0.029 kg/hr), less than 52 kg/hr would be accounted for. Addition of a conservative estimate of 52 kg/hr from Type 3 leaks and the loss through the equalization ports of a further 18 kg/hr accounts for only 70 kg/hr. This indicates the existence of at least one larger leak unidentified by the soap solution method.

Examination of the volumetric flowrate of the non-contaminated exhaust system (85 m³/s for each unit) suggests that the relatively small 17 nL/L tracer concentration in the stacks of Units 2 and 4 could represent approximately 300 kg/hr out of a containment leakage estimated at 1000 kg/hr (see Appendix 3) from measurements taken at the same time as the stack concentrations. However, given the relatively large uncertainties involved it is quite possible that this represents either the bulk of the measured leakage or just one of several major leaks which together represent the measured leakage.

The exhaust fans ventilate each auxiliary bay from the 693' elevation. The layout of the station and an examination of airflow patterns/9/ indicates that this exhaust air is drawn primarily from levels 678' and 693', and prior to that probably originates from lower down in the auxiliary bay. Measurements of turbine hall air on 639' near Unit 2 found no ethylene and the ambient levels from lower sections of the reactor auxiliary bay were generally in the 2 - 6 nL/L range. Therefore it seems likely that the tracer was being released in the upper two levels. The relatively high concentrations of ethylene in the boiler rooms of both Units 2 and 4 lend support to this explanation. Leakage from the boiler rooms or the reactivity mechanisms deck area could be entrained directly upwards via the ventilation flows towards the roof fans with little horizontal diffusion that could be detected by other gas sampling.

Even if the existence of leaks at the top of Units 2 and 4 is considered, approximately 35% of the measured leakage rate has been accounted for. Other possible sources of leakage are the vacuum building, the fuelling machine duct and the pressure relief ducts. It was not possible to examine the latter two areas as planned using ultrasonics since it was decided that unless the maximum allowable leakage rate was exceeded no personnel would enter containment because of elevated tritium levels (up to 2000 MPCa).

It should be noted that despite the high leakage rates found during independent testing of the vault vapour recovery systems tracer gas measurements around these systems found no evidence of ethylene thus implying the integrity of the isolation blanks used during the pressure test.

The data and analysis in the foregoing discussion indicate that, when employed as an area sampling method, the tracer gas technique is neither as efficient nor reliable as the soap solution method for locating smaller Type 3 leaks (or Type 1 and 2 leaks). However, the soap solution technique is both incapable of detecting unsuspected leaks and too labour- and time-intensive to employ indiscriminately. The leak catcher results and the calculation in Appendix 3 indicate that these smaller leaks are not significant compared to the total measured station leakage.

To make significant inroads on total leakage it is clearly necessary to find the few larger unexpected leaks which make up the bulk of measured leakage. The most suitable method is the tracer gas technique. The tracer gas technique also has the advantage of reducing work and dose requirements in radioactive or difficult-to-reach areas such as moderator rooms or PHT pump areas, respectively. It would be impractical to take large numbers of additional tracer gas samples to check all penetrations suspected, from commissioning tests, of having small leaks which are not easily detected by the method. The soap solution technique is still useful for these smaller, suspected leaks. For those leaks that exist in portions of the containment boundary which is underground (eg. the FMD), ultrasonic testing is the best presently available alternative.

More emphasis should be placed on defining the significance of leaksites. This will now be possible with the use of the leakage catcher and will allow attention to be focussed on those leaks which truly represent significant leakage rather than any leak which is capable of blowing away soap solution.

5.0 CONCLUSIONS

1. The tracer gas technique was effective in detecting the various leak site types including many Type 3 leaks and unexpected leaks. Evidence of a potentially significant leak was detected in the upper two levels of Units 2 and 4. The tracer gas technique was also found to be useful both in areas where the potential radiation dose to personnel is too high for the more time-intensive application of soap solution and in hard-to-reach areas where preparation for soap application would be labour-intensive.
2. Ethylene was demonstrated to be a suitable tracer gas which was easily detected at low concentrations by the gas chromatography method used.
3. The leakage catcher was able to quantify leakage rates from identified sites and therefore indicate the severity of the leak. Quantification of several Type 3 leaks, which were

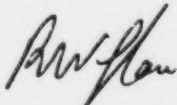
identified by soap solution, indicated that such leaks are insignificant relative to the measured total containment leakage rate.

6.0 RECOMMENDATIONS

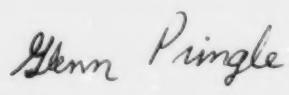
1. The tracer gas leak detection technique should be considered as a primary leak detection method for future pressure tests of this nature.
2. Through organization and strategy refinements the technique can be improved (eg, an overall leak search director to facilitate the interpretation and implementation of tracer gas results).
3. Better leakage information is available at higher pressure. Therefore it is desirable that the initial leak search not begin at less than 15 kPa and that a subsequent leak search be conducted at 69 kPa after peak pressure has been attained.

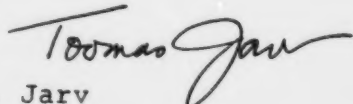
4. On-power sampling of the reactor vault air should be conducted periodically after a tracer test (such as the 1987 outage at Bruce NGS 'A') to investigate the decay of ethylene concentration with time.

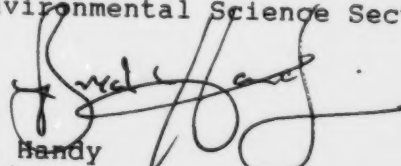
Approved by:


for O.A. Kupcis
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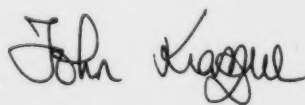
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APPENDIX 1

Evaluation of 13X Molecular Sieve for Ethylene Adsorption

In order to use ethylene as a tracer gas it was necessary to determine the extent of ethylene absorption on the 13X molecular sieve used in the vault vapour recovery driers. This was done to provide assurance that explosive concentrations of the tracer gas (LEL 31 mL/L) would not accumulate in the drier regeneration circuit.

The series of tests consisted of flowing known concentrations of ethylene through a pre-weighed column of 13X molecular sieve. The weight of the column was measured and the ethylene absorbed was calculated when there was no further change in either ethylene exit concentration (as measured by gas chromatography) or sieve weight.

Test 1 - 50 uL/L Ethylene

Weight of 13X before test:	23.11102g
Concentration of Ethylene:	50.2 uL/L in dry air
Flow of ethylene:	4.81 L/min
Temperature:	24°C
Weight of 13X after test:	23.11123 g
Weight Gain:	0.00021 g

Test 2

Test 2 consisted of flowing dry air through the same column of 13X for 911 seconds.

Weight of 13X before test:	23.11123 g
Weight of 13X after test:	23.11105 g
Weight Loss:	0.00018 g

Test 3

To confirm that the weight gain and loss in test 1 and 2 were due to ethylene and not trace moisture in the air supply, the test was repeated using new dry 13X and a flow of air with no ethylene added.

Weight of 13X before test:	23.13405 g
Flow of air:	4.81 L/min
Weight of 13X after test:	23.13405 g
Weight Gain/Loss:	0.00000 g

Test 4 - 30.2 mL/L Ethylene

Weight of 13X before test:	23.79733 g
Concentration of ethylene:	3.02% in dry air
Flow of ethylene:	4.81 L/min
Temperature:	24.5°C
Weight of 13X after test:	24.10438 g
Weight gain:	0.30705 g

Test 5 - 15.1 mL/L Ethylene

Weight of 13X before test:	23.14422 g
Concentration of ethylene:	1.51% in dry air
Flow of ethylene:	4.81 L/min
Temperature:	24.0°C
Weight of 13X after test:	23.36263 g
Weight Gain:	0.21841 g

From the results above, the limits of ethylene adsorption can be seen for various ethylene concentrations in the gas phase. With 622 Kg of molecular sieve in each drier bed the maximum loading would be equivalent to 5.65 L of pure ethylene at 20°C. The free volume of each main drier bed alone is approximately 4.5 m³ and represents the bulk of the regeneration circuit volume with smaller volumes in the heaters and condensers/10/. With an estimated 5.65 L of pure ethylene released from the regenerating drier bed this represents a maximum concentration of 1.3 mL/L (cf LEL of 31 mL/L). This concentration is a very conservative estimate since water vapour will preferentially displace much of the ethylene during the adsorption cycle thus effectively reducing the capacity of the drier bed for ethylene.

During the drier cooling cycle this ethylene will be readsorbed on the bed to some degree. Ethylene will continue to concentrate in the regeneration circuit with each cycle until the amount readsorbed at the higher concentration in the regeneration circuit is equal to the bed loading during drying of the vault air at an ambient concentration of 50 uL/L. Assuming a conservative linear relationship between 50 uL/L and 30 mL/L this equilibrium will most likely occur at a concentration insignificantly greater than 1.3 mL/L ethylene. Therefore no explosive hazard exists from ethylene concentration in the regeneration circuits of the vapour recovery driers.

Unpublished and unconfirmed data (only three data points) provided by Union Carbide/11/ for 13X powder indicates that 4.8 g of ethylene would be absorbed per 100 g of sieve, significantly greater than the 0.94 g/g sieve reported here. Based on data for 4A sieve powder and pellets, the pellets are expected to absorb approximately 25% less than the corresponding powder. No

explanation for the remaining discrepancy was evident. However, even if the Union Carbide figures are accepted the ethylene concentration in the drier regeneration circuit would not exceed approximately (6 mL/L) significantly lower than the LEL (31 mL/L).

Eventually the declining concentration in the reactor vaults, due to purging required to maintain negative containment pressure, would cause ethylene to leave the regeneration circuit.

APPENDIX 2

Details of Sample Collection and Analysis

TEDLAR (Dupont) polyvinyl fluoride bags, each connected to a small battery-powered (1.5v) and switch-operated pump, were used for air sampling. In two hours approximately 200 of these were placed throughout the station by 12 Bruce Operations personnel, each of whom performed up to four trips with 2 to 7 samples each. Each motor was activated manually and left to run for approximately 2-10 minutes (filling time 30 minutes). The bags were sealed mechanically with butterfly clamps and returned to the field laboratory for analysis. Sampling commenced at 2000 EST on May 12 at a containment pressure of approximately 6 kPa and ended at 2200 EST of the same day (13.8 kPa). A further 90 samples were obtained during the remainder of the test. Sampling bags with timer operated pumps, protected from contamination by plastic bags, were also placed inside containment to confirm the vault ethylene concentration.

A Varian Model 3400 gas chromatograph equipped with a flame ionization detector (FID) was used to analyse the air samples. The signal from the detector was recorded on a Varian Model 4290 signal integrator.

A VALCO multi-functional ten-port valve, with stainless steel body and a VALCON 'S' core, was equipped with a 1 mL stainless steel sampling loop and used as the gas sampling valve. The valve was fitted with 0.159 cm zero volume fittings. The valve was heated inside the chromatograph oven. Low volume stainless steel connections were used in all critical areas.

The carrier gas was ultra-pure nitrogen (N_2) and was passed through a purification train consisting of oxygen, hydrocarbon and molecular sieve traps. The carrier gas flowrate through the column was 50 mL/min during sample analysis. The ethylene detection limit was approximately 20 uL/L. All delivery tubing to the instrument was stainless steel.

The column used for separating the ethylene from the other air sample components was a 1.5 m x 0.318 cm OD stainless steel column packed with 60/80 mesh Carbosieve G and conditioned by passing a flow of 30 mL/min of carrier gas (N_2) through at a column temperature of 165°C for two hours. The detector temperature was set at 300°C and the column temperature was maintained at 165°C during sample analysis.

Each sample was attached to the inlet side of the GC sampling loop system. A metal bellows pump drew the sample from the bag through the sample loop at about 150 mL/min. After adequate flushing, the

samples was then injected onto the column and the chromatograph recorded. Total analysis time per sample was approximately 2 minutes.

GC Calibration

A primary standard of ethylene in nitrogen was purchased from Matheson of Canada Ltd. The concentration of the working standard was 1.00 ± 0.05 mL/L. A single stage dynamic dilution system was used to generate trace gas mixtures of ethylene in air. The dilution system was made up of two Tylan Mass flow controllers with the working standard fed through a 500 mL/min controller at the required flow and this flow was then diluted with air, from a zero air cylinder, which was fed through a 5000 mL/min controller, again at the required flow. Stainless steel connections were used throughout the system and all flows were standardized to NTP (101.3 kPa and 25°C).

A known concentration of ethylene in air was drawn from the dynamic dilution system through the sample loop on the 10-port valve. After adequate flushing, the sample was then injected onto the column and the chromatograph recorded. The ethylene response for the flame ionization detector of the gas chromatograph used during the study was found to be linear.

Additional Equipment

A PHOTOVAC Model 10S50 portable has chromatograph equipped with a photoionization detector (PID) was also used to analyse air samples. The carrier gas used was ultrapure N_2 that was passed through a purification train similar to the one used for the Varian 3400 GC. The column used in the 10S50 was a 2.4m x 0.318 cm OD Teflon tubing packed with 1.5% XE-60/1% H_3PO_4 on Carbopack B, 60/80 mesh. The injection volume was 1 mL and the detection limit for ethylene was approximately 2 nL/L.

The analytical measurements were divided into three categories as follows:

- (a) trace or negligible amounts of ethylene, <10 nL/L were measured with the Varian or <2 nL/L with the Photovac.
- (b) qualitative detection where 10 - 20 nL/L were measurable with the Varian or 2-5 nL/L with the Photovac
- (c) quantitative detection where >20 nL/L were measured with the Varian or >5nL/L with the Photovac.

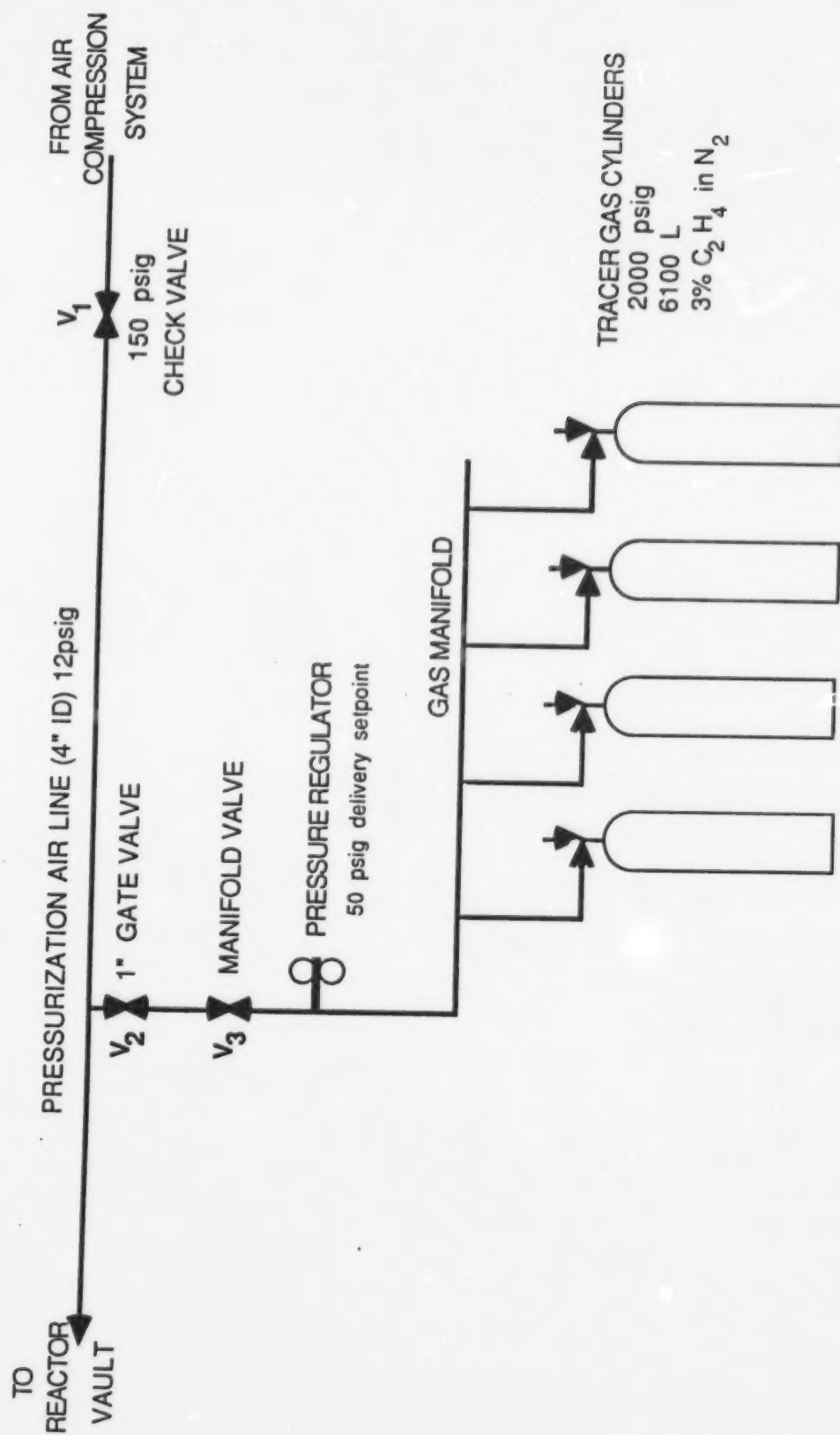
APPENDIX 3

Noncontaminated Stack Leakage Calculation

Assuming approximately 1800 penetrations listed as EP's and using the largest flow measured by the leak catcher as an average Type 3 leak flowrate, then the maximum flow accounted for by penetration leakage would be 52 kg/hr (1800×0.029 kg/hr) compared to a rate of 1000 kg/hr at 40 kPa measured at the same time as the stack measurements.

The measured tracer concentrations in each of non-contaminated exhaust stacks #2 and #4 was 17 ± 5 nL/L with an airflow of $85 \text{ m}^3/\text{s}$ in each stack. From turbine hall and reactor auxiliary bay measurements a conservative background would be 5 ± 3 nL/L. At 14 kPa the tracer concentration in containment was measured to be 41 ± 2 uL/L and, assuming negligible tracer loss via leakage and accounting for a test vent on May 13, a conservative tracer concentration estimate would be 30 ± 5 uL/L in containment at 40 kPa on May 14 when the exhaust stacks were sampled.

From the foregoing assumptions, approximately 300 ± 160 kg/hr of leakage can be accounted for in the two uncontaminated exhaust stacks #2 and #4. Given the uncertainties, this constitutes a significant fraction of the 1000 kg/hr measured at 40 kPa.



APPENDIX 4

FIGURE 4.1 : INJECTION SYSTEM FOR TRACER GAS.

